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1.0 Overview of Findings

1.1 Proposed Requirements

With the coming implementation of the GPS Wide Area Augmentation System (WAAS), an opportunity exists for a significant transition from traditional ground-based navigational aids to a satellite-based system. This could eventually lead to a considerable reduction in the number of navigational aids required to support the National Airspace System (NAS). This study examines the costs and benefits of LAAS as a system to complement the capabilities of WAAS, and was prepared in anticipation of a planned Key Decision Point 2 (KDP-2) for LAAS in February 1996.

1.2 Alternatives Considered

The following alternatives were considered:

1. Code-based LAAS with Pseudolite
2. Pseudolite Kinematic Carrier-phase LAAS
3. Wide-Lane Kinematic Carrier-phase LAAS
3. Expansion of Category II/III Instrument Landing System (ILS) network

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The reference case, against which the alternatives were compared, was retention of the current number of Category II/III ILSs, together with Category I ILSs outside the continental United States (Alaska, Hawaii, Puerto Rico, etc.). It was assumed that existing Category II/III ILSs would be replaced with new Mark 20 ILSs in 1998 and that WAAS would be used for precision approaches within the continental United States, non-precision approaches, and en route navigation.

1.3 Costs and Benefits

Quantified LAAS benefits to aviation users and to the government total an estimated $2.58 billion constant 1995 dollars over the 2001-2017 period, with a present value of $885 million. The total cost to the FAA and to users is $327 million, with a present value of $211 million. This results in a net present value (NPV) of $674 million with a benefit/cost (B/C) ratio of 4.2.

Benefits of the ILS alternative over the same period total an estimated $2.24 billion constant 1995 dollars, with a present value of $811 million. The total cost to the FAA and to users is $430 million, with a present value of $196 million. This results in an NPV of $615 million with a B/C ratio of 4.1.

The cost figures above include expenditures for aircraft avionics, ALSF-2 approach lighting systems, and runway visual ranges, all of which will be required to achieve the benefits shown. Costs for only the LAAS program are estimated at $35 million for research, engineering, and development (RE&D), $98 million for facilities and equipment (F&E), and $43 million for operations and maintenance (O&M), with present values of $28 million, $63 million and $16 million, respectively. In current dollars, total RE&D funding required is $39 million, total F&E funding required is $117 million and O&M over the 17-year period is $66 million.

1.4 Conclusions and Recommendations

Expansion of precision landing capabilities in the NAS provides substantial user benefits. The recommended method of expansion is with LAAS. Quantified benefits of LAAS are slightly greater than those of ILS expansion, and the omnidirectional coverage and lower unit cost of LAAS give it the potential to enable considerable benefits beyond those quantified in this report.

2.0 Introduction

“The FAA has the statutory authority to acquire, establish, operate and maintain navigation facilities for all phases of flight. This mission must be performed to ensure navigation service is available where needed in a cost-effective manner. In order for the FAA to effectively accomplish this mission, a satellite navigation capability with the required integrity, continuity, accuracy, and availability must be provided. This capability should support (1) all-weather operations for all phases of flight, (2) air traffic capacity enhancements, and (3) future technology enhancements.

The Department of Defense (DOD) Global Positioning System (GPS) provided a practical starting point for the eventual development of a Global Navigation Satellite System (GNSS). However, GPS as designed, developed, and deployed by the DOD, will not totally satisfy all civilian aviation needs for navigation and landing. For use in civil aviation, augmentations will be required to improve GPS accuracy, integrity, continuity, and availability. The Wide Area Augmentation System (WAAS), is designed to meet navigation and landing needs down to or near the lowest Category I decision height of 200 feet. Where the WAAS is unable to meet these needs ..., a local area augmentation system is required. In addition, a local area augmentation system is required to meet the more stringent CAT II/III needs that exist. Outside of the aforementioned requirements, the local area augmentation system will also provide an all weather surface navigation capability. (Operational Requirements Document, February 28, 1995; FAA Act of 1958, section 307; 1994 Federal Radio Navigation Plan, p. C-4)” (Ref. 13)

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“The international civil aviation community is divided on the issue of future precision approach and landing systems. Rather than choosing one common architecture, the International Civil Aviation Organization (ICAO) has, at the Montreal meeting in April 1995, given member countries the option to choose their own architectures. The U.S. position reflected an already taken decision and another still pending. For CAT I service in the NAS, the FAA has selected [WAAS]. A decision on the future CAT II and III landing system architecture, however, is still pending.” (Ref. 12)

The mission need for GPS augmentations was given KDP-1 approval in October 1992. As part of that decision, WAAS was separated from LAAS. Since that time, extensive research has been undertaken to evaluate the feasibility of LAAS for Category II and III precision approaches. The program office now has a high level of confidence that even code-based LAAS (a simpler and less costly alternative than carrier-phase LAAS) can meet FAA requirements for Category III approaches. KDP-2 for LAAS is planned for February 1996.

This analysis covers the use of LAAS to meet the FAA’s requirements for precision approaches that cannot be satisfied with WAAS. The reference case of existing ILSs is compared with expansion using LAAS and with expansion using ILS. While LAAS has considerable additional potential for use on airport surfaces, benefits and costs of realizing that potential were not quantified in this analysis.

3.0 Existing and Planned Capabilities

3.1 Existing Capabilities

Precision approach and landing requirements are presently met by ILS and, to a limited extent, by the Microwave Landing System (MLS). ILS, while a well proven technology, requires extensive effort to install and cannot be used at some locations because of siting restrictions. ILS is also subject to frequency problems: a restricted number of available frequencies has led to frequency congestion, and older receivers are subject to interference from some FM radio frequencies.

3.2 Planned Capabilities

FAA has certified GPS to be a supplemental means of navigation for en route, terminal, and non-precision navigation (TSO 129). Because of the accuracy, worldwide coverage and flexibility provided by GPS, it is expected that nongovernment civil use will grow rapidly. WAAS, with its improvements to GPS integrity, availability, and accuracy, is expected to satisfy the FAA requirements for primary means non-precision approaches after its initial deployment (expected date 1998), and for Category I precision approaches after it is fully deployed (expected date 2001). WAAS will not, however, satisfy the FAA requirements for Category II or III precision approaches, nor will it satisfy the requirements for Category I approaches outside the continental United States.

The LAAS program is intended to satisfy FAA precision approach requirements where WAAS cannot. In addition, the nature of the LAAS signal allows the user to have highly accurate position information anywhere in the airport vicinity, enabling the potential use of LAAS as a surface navigation sensor and an input to surface surveillance/traffic management systems. Other facilities in the LAAS coverage area, such as helicopter landing zones, may also be able to take advantage of the LAAS signal.

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4.0 Alternatives Assessed

4.1 Descriptions

The following descriptions are from Anand Prabhakar (Ref. 12)

The Pseudolite Kinematic LAAS architecture uses a pair of integrity beacons that are placed on the ground adjacent to the approach path to a runway. They transmit low-power GPS-like signals in the L1 band (1575.42 MHz). Powered by low-voltage batteries (about 9 volts), each broadcasts a signal to a limited area “bubble.” The “bubble” has an upward range of only a few times the approach height. This architecture is carrier based. The GPS code is used only to identify satellites whose carrier signals are used in solving for the position fix. The GPS receiver measures instantly only the fractional component of the carrier phase; the integer cycle components must be determined from the ground and uplinked to the aircraft. One determined and broadcast to the aircraft, the cycle count is coupled with the aircraft attitude information by the GPS receiver to fully resolve the phase cycle ambiguities in the airborne receiver.

The Wide-Lane Kinematic LAAS architecture uses carrier phase measurements but does not require any GPS-like ground transmitters. Carrier phase measurements are taken on both GPS frequencies: L1 (1575.42 MHz) and L2 (1227.60 MHz). Satellite clock errors are removed by comparing L1 and L2 phase data from the same satellite. The dual frequency measurements are also combined to cancel out any ionospheric delays. To remove ambiguities due to uncertainty about carrier cycles, the carrier phase measurements are complemented with combined code measurements and filtered. Results are broadcast to the aircraft to resolve the ambiguities in the airborne receiver.

The Code-based LAAS architecture uses L1 receivers on the ground and in the aircraft to obtain code phase measurements. Low noise pre-amplifiers and narrow correlator receivers are used, and the measurements are than carrier smoothed to minimize noise. Ionospheric effects are corrected using parameters from ionospheric modeling. The ground reference station data, raw pseudorange data and Selective Availability range-rate corrections, is uplinked to the aircraft once per second.

The ILS architecture has three main components: glide slope, localizer, and marker beacons. Glide slope (UHF) and localizer (VHF) carrier signals are modulated by audio tones, and the null between the modulated signals defines the approach path. Any deviation from the course is computed as a difference magnitude call Difference in Depth of Modulation. Marker beacons radiate vertical fan-shaped beams, and are used to indicate defined points along the approach path.

4.2 Assessments

The pseudolite kinematic and wide-lane kinematic LAAS provide the same basic benefits as code-based LAAS, but require greater cost and complexity of receivers. They were included because there was some doubt initially as to whether code-based LAAS could achieve the required accuracy, integrity, availability, and continuity of service to accomplish FAA-approved Category II and III precision approaches. That doubt has been resolved, and the program office is now confident that code-based LAAS can meet all requirements.

ILS is based on mature, proven technology, and the short-term costs of continuing to use ILS for Category II and III requirements are lower than the costs of converting to LAAS. The long-term view, however, favors LAAS. Some of the reasons are stated below.

a. The incremental cost of a LAAS station is significantly less than that of an ILS, so any further system expansion would be less expensive with LAAS.

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b. LAAS provides accurate position information anywhere in the airport vicinity; ILS provides information only along the approach path to one runway.

c. Some sites (such as LaGuardia and Juneau) have siting or geographic limitations for ILS; those limitations do not exist with LAAS.

d. Implementation of LAAS would enable users to remove (or not install) ILS equipment and operate a seamless satellite navigation system; without LAAS, they would need GPS/WAAS for most applications and ILS for Category II/III and/or operations into areas such as Alaska.

5.0 Ground Rules and Assumptions

a) Benefits are assumed to exist in the following areas:

User efficiency: avoidance of cancellations, diversions, and delays due to low ceiling/visibility at the departure or destination airport.

Avionics savings: cost comparison of GPS receivers with the avionics replaced by GPS.

FAA savings: avoidance of capital expenditures for replacement navigation systems; reduced maintenance of LAAS compared with existing systems.

b) A single LAAS ground station was assumed for every location, even those with multiple ILSs. The rationale was that there was sufficient redundancy within the ground station subsystems to ensure required availability. It was also assumed that the station would be sited such that it be unlikely to suffer catastrophic failure from ground operations (i.e. runway snow removal).

c) Manpower requirements for maintenance of present inventory ILSs were based (in part) on the Navigation and Landing Resource Requirements Study developed by the FAA O&M Team, dated March 1993 (note: data from this study, as applicable, are consistent with those used in the WAAS CBA, completed in late 1994). Quantities of maintained equipment used were those applicable to the LAAS CBA. Unit costs were updated as to 1995 appropriate values.

d) Only elements subject to future decommissioning were addressed (e.g. glide slopes, localizers, markers) viz. elements needed with either ILS or with LAAS (e.g. approach lights, RVRs, etc.) These manpower costs (equipment specific) were supplemented by ancillary additional (system specific) costs consisting of Local Consumption, Logistics Support, Operational Support, Training, and Flight Inspection.

e) Only one configuration of quad-redundant ground station was assumed for CAT I/II/III in order to simplify certification, site planning, and maintenance considerations.

f) The avionics costs for LAAS are predicated on the prior equipping of aircraft to a WAAS capable standard. There is no conceptual difference between applying a WAAS correction versus applying a LAAS correction. Transmission of the correction signal is expected to be over the L1 frequency, eliminating the need for a separate data link receiver.

g) The Department of Defense is assumed to cover the costs of both the space and ground control segments of the GPS constellations for the duration of the program. It is also assumed that they will agree to the concept of allowing transmission of differential corrections to the L1 C/A code GPS signal.

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h) ILS will be decertified during the period 2007-2011. Only those ILSs providing Category II/III capability at an airport's second or third runway will be decertified in 2007, and most ILSs will be operational through 2010.

i) In determining life cycle costs for principal mission equipment, the assumption was made that major components would be replaced every five years. A minimum amount of repair parts would therefore be necessary. This assumption is based on the rapid advancement in technology noted in computer and electronic equipment and the high reliability of solid state circuitry. Replacement costs were classified as recurring costs.

j) It is assumed that the FAA will not incur responsibility for funding the GPS space segment or control segment. Both segments are currently operated and funded by the Department of Defense.

k) Office of Management and Budget (OMB) guidelines are used for cost conversions. For budgeting estimates, costs are converted to current year dollars using OMB inflation rate guidelines of January 1994. For cost-benefit analysis, costs are converted to present value using a 7 percent annual discount rate in accordance with OMB Circular A-94, revised October 29, 1992.

l) DOD will agree to WAAS implementation for accuracy.

m) Surface Navigation: The presence of GPS LAAS, a precise navigation and guidance tool, on the aircraft presents the opportunity to use this capability to great advantage as a navigation device on the surface of the airport. In poor visibility conditions, such a capability could significantly enhance taxi operations and offer important safety benefits by assisting air crews with location awareness on the airport movement areas. Procedures could also be implemented which would assist with reducing accidental runway incursion. These capabilities will not be available solely because GPS LAAS is on board, however. Specific actions must be taken to provide mapping data of the taxiways and movement areas of the airport to the air crews, and a means of overlaying that data with the real time data provided by the LAAS must be devised. These are technologically achievable today, but they have not yet been accomplished. The costs of the potential additional capabilities is unknown, for the architectural design of such a system has yet to be decided. Therefore, costs and benefits of the potential surface navigation function are not addressed in this study except to say that their availability could provide an important safety and efficiency service during low visibility conditions and their relative costs and benefits should be the subject of further analysis.

n) CAT II/III LAAS will be installed at airports which currently are equipped with CAT II and CAT III ILS.

o) CAT I LAAS will be installed at airports which currently are equipped with CAT I ILS but which lie outside of the WAAS coverage area. WAAS will provide CAT I landing service at current CAT I ILS equipped airports which are within the WAAS area of coverage.

p) CAT II/III LAAS will be installed at airports which currently do not have CAT II or CAT III capability but which qualify for this capability under current establishment criteria.

q) CAT I LAAS will be installed at new CAT I qualifying airports which are outside of the WAAS coverage area.

r) LAAS avionics equipment will be installed at varying rates depending on category of aircraft. It was assumed that avionics would be installed in the aircraft inventory at the following rates and over the times indicated:

Air Carrier	100 percent over a three year period
Air Taxi	100 percent over a three year period
General Aviation (High End)	60 percent over a four year period
General Aviation (Low End)	25 percent over a five year period
Military	100 percent over a two year period

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s) Climatological data from the Ceiling and Visibility Climatological Study were used, by airport, where available. These specific data were available for most of the airports analyzed in the study, but at airports for which the individual data were not available, regional data were substituted so as to represent the actual weather history as closely as possible.

t) Airport landing activity by airport was calculated by halving itinerant operations statistics available from the Terminal Area Forecast Data Base. Years not covered by the TAF Data Base were extrapolated to the year 2017.

u) Costs of disruption (delay, diversion and cancellation) were calculated using figures from the FAA publication “Economic Values for Evaluation of Federal Aviation Administration Investment and Regulatory Programs.“

v) Passengers per aircraft at each airport were calculated by using air carrier enplanement and itinerant operations figures from the terminal area forecast data base.

w) Costs for passenger value of time, aircraft direct operating costs and other costs were calculated using figures from the Precision Approach Establishment Criteria.

x) Costs per disruption were calculated according to guidance contained in Establishment Criteria.

y) Savings from safety enhancements were not attributed to LAAS since it will predominantly be installed where a precision capability is already in place at the destination and alternate airports. Safety benefits are based on going from nonprecision to precision approaches, not Cat I to Cat III.

z) Because of uncertainties as to architecture and associated additional costs, the benefits of LAAS for vertical flight operations were not quantified in this study.

aa) Costs and benefits are calculated through 2017.

6.0 Methods and Data Sources

6.1 Cost Estimating Methods and Data Sources

A representative ground station configuration was developed based on the components necessary to determine a GPS position, compute differential corrections, and transmit those corrections to a radius of approximately 20nm. Once a configuration list was created, multiple electronics manufacturers were contacted for pricing information on similar components. List prices were utilized in order to ensure that a profit fee would not have to be determined for the station. Most avionics manufacturers stated that a volume order from a major airline or government agency would result in a 15-25% reduction in the catalog or list price.

The primary driver of both the ground station and avionics costs is the GPS sensor itself. The units developed for airborne use are also eminently suitable for use in the ground station. Twelve channel sensors were selected to maximize the number of satellites that could be used in computing a position solution and correction.

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There are currently five teams of manufacturers developing differential ground station under the SCAT I program. Both the Honeywell/Pelorus and Interstate Electronics/Airport Systems International teams were contacted with respect to their ground station configurations, design philosophies, and rough cost estimates. Their openness was somewhat limited by the intensely competitive nature of SCAT I, the recent award of the WAAS, and the yet to be accomplished LAAS contract. However, they provided good sanity checks of overall costs and configuration assumptions used in this analysis.

There are a number of avionics manufacturers already producing sophisticated GPS sensors and navigation systems. The jump from a generic GPS box to one capable of accepting differential corrections, especially those transmitted over the L1 frequency, is extremely small. All that is required is a software change to recognize the pseudo-random noise (PRN) code of the differential signal, which looks just like an ordinary GPS satellite message, and then apply the correction to its position solution. A WAAS-capable box operates in this manner, as will LAAS. Therefore, costs for current top-of-the-line GPS avionics should be very close if not indistinguishable from LAAS avionics. Product brochures, catalogs, and list prices were received from the following manufacturers to determine representative avionics costs:

Trimble	Canadian Marconi	Sextant
Interstate Electronics	Magellan	Narco
3SNavigation	Litton	Universal Navigation
Ashtech	Bendix/King	Arnav
Garmin		

Two major airlines are in the middle of accomplishing GPS upgrades to their existing fleets, Alaska Airlines and American Airlines. The lead avionics engineers for each of these modification programs was interviewed extensively by telephone. A great deal of information was obtained about the amount and scope of work required to modify a portion of their fleets, along with detailed cost information. The modification work covers a number of the issues that are applicable to LAAS such as integration into existing flight management systems, autopilots, and cockpit panels/switches.

6.1.1 Project Management and 6.1.2 Systems Engineering:

A maximum program office strength of 40 people was assumed for LAAS program management and systems engineering. This is approximately the size of the WAAS program office, which is managing a project that is similar in nature. A yearly personnel cost of $100K per person was assumed. The split between program management and systems engineering was assumed to be approximately 40/60 at its peak during production and deployment, and resulted in the profile below.

	FY95	FY96	FY97	FY98	FY99 to FY05	FY06	FY07 to FY15
Project Management	3	5	10	15	15	10	3
Systems Engineering	3	5	15	20	25	15	2

In addition, continuing systems engineering activities are expected at the two universities performing demonstration programs currently. The expected level of funding is $5M in FY96-97, increasing to $6M in FY98 and continuing through the first year of production (FY01).

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6.1.3 Pre-Production Systems

6.1.3.2 Rapid Prototype: A competitive prototype evaluation from two vendors is assumed in FY98. Each vendor is expected to produce three prototype systems, for a total of six at $250K per system (see 6.1.4.1 for system cost breakdown). Each system is then upgraded at $100K each (50% of hardware cost) in FY00 for continuing test and evaluation purposes.

6.1.3.3 Prototype System: Source selection of a winning contractor is assumed in FY99, with a contract to be placed for three production-standard systems at $250K each.

6.1.4 Prime Mission Equipment

6.1.4.1 Hardware: A total buy of 160 ground stations is assumed at a rate of 40 per year from FY01 through FY04. A single configuration for CAT I/II/III was assumed as this would simplify the manufacturing, maintenance planning, and certification of the system. Providing a quad-redundant system allows for maintaining CAT III operations during maintenance or after the failure of one subsystem. The cost of the ground station was determined using a bottom-up component method, plus 10% for design uncertainty. The breakdown is as follows:

Item	Qty	Unit Cost	Total Cost
Processing & Control Unit (4 CPUs)	1	$25,000	$25,000
GPS Sensor	4	$25,000	$100,000
GPS Antenna Assembly	4	$5,000	$20,000
Uninterruptable Power Supply	1	$7,000	$7,000
L1 Transmitter w/antenna	4	$5,000	$20,000
Remote Status Unit	1	$10,000	$10,000
Subtotal			$182,000
10% Design Uncertainty			$18,000
Hardware Cost (6.1.4.1)			$200,000
Installation (6.1.12)			$20,000
Minor Construction (6.1.15)			$30,000

The 10% for design uncertainty should cover the cost of a VHF data link (VDL) ~~if it is~~should it be determined that transmitting corrections over the L1 frequency is not practical. The cost for the L1 transmitters should remain however as they will be necessary if the final LAAS design incorporates pseudolites. Multiple GPS and electronics manufacturers were surveyed for costs of their respective components, and list prices or higher were used. The most costly and critical item was the GPS sensor itself and the highest cost quoted was $25,000 for a 12 channel unit. Most 12 to 15 channel units were quoted in the $15,000-$17,500 range.

The basic assumption used in determining LAAS avionics costs is that aircraft will have already equipped with a WAAS-capable GPS avionics fit. It is also assumed that these avionics will be integrated into the current flight director, electronic flight information system (if so equipped), and autopilot to allow CAT I landings. Given this configuration as a starting point, the modifications required to accommodate CAT II/III landings are relatively modest (Figure 6.1).

The addition of a ventral antenna to adequately receive LAAS signals is anticipated, and has been priced at $2K installed (a single antenna is adequately reliable for CAT III operations) for an air carrier quality design. However, a ventral antenna is susceptible to multipath signal errors and may not be the preferred solution for LAAS. It is unknown whether the current dorsal “patch” antenna that is adequate for TSO C129 and WAAS will have sufficient performance for LAAS. If not, then perhaps replacing the dorsal antenna with a blade-type would be required. More than likely, some sort of antenna addition or replacement would be required to transition from WAAS to LAAS, and so $2K per aircraft is a reasonable assumption.

A software upgrade is all that is envisioned for making a WAAS receiver capable of processing LAAS signals (as a point of reference, Magellan advertises a software upgrade from a vanilla GPS/FMS to WAAS). This is due to the assumption that the LAAS correction message will be of identical form to the WAAS message, the only difference being the source of the correction and the ability of the box to recognize the PRN code identifying that source. The method of transmission is expected to be over the L1 frequency for both WAAS and LAAS. Should it become necessary to employ a VHF data link instead of L1, the cost of adding the receiver(s) to the aircraft would have to be included if not already provided due to another program such as automatic dependent surveillance. A number of currently available GPS boxes make provision for separate data link input. The software upgrade has been priced at $4K per aircraft, independent of the number of GPS boxes onboard. This is analogous to the updating of flight management system (FMS) software. Boeing quotes the cost of enabling GPS functions in the 737 FMS at $4K per aircraft, and the crossfill function is utilized to update all the FMSs onboard without additional charge. It is felt that the competitive pressures of the GPS market will result in similar pricing for these updates, especially as more and more panel-mount FMSs have embedded GPS circuitry. As a price comparison, Trimble’s general aviation GPS avionics have

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a differential of $1.5K between equipment with and without approach capability. High-end general aviation GPS equipment is roughly one-half the cost of airline-quality GPS sensors, and doubling the $1.5K differential results in a $3K upgrade cost versus the $4K used.

To be conservative, some modification to either the flight management system or flight control computer software is anticipated, again estimated as above at $4K per aircraft. Due to the transition period from CAT II/III ILS to LAAS (or for that matter from CAT I to WAAS) there is a need for the aircraft to recognize when an ILS approach is being performed by the pilot (ILS VHF frequency dialed in) versus a LAAS approach (entering in such data as 3-letter airport identifier and 3-character runway designation). Given the layout shown in Figure 6.1, the WAAS/LAAS box could handle the signal selection internally with simple Boolean logic. If an appropriate ILS frequency is entered on the VHF navigation receiver, then the outputs of the localizer and glideslope are sent to the autopilot/flight director; if not, then the GPS-generated outputs are used. At least one avionics manufacturer is utilizing this approach in its products. Use of the flight management system would be limited to data entry of airport and runway identifiers, and it is expected that the software to accomplish this limited function would be certifiable. No additional flight control changes are anticipated, since the GPS avionics are capable of emulating the current ILS receiver(s) output.

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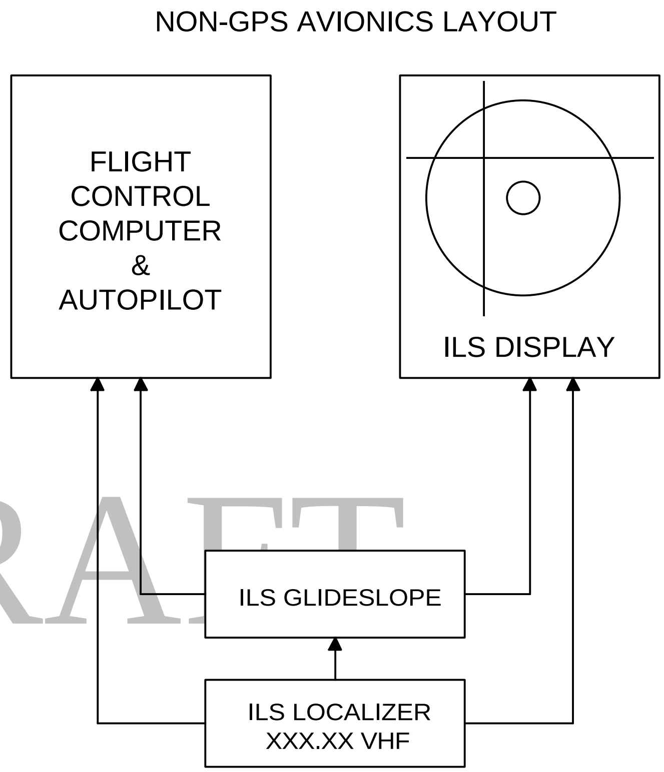
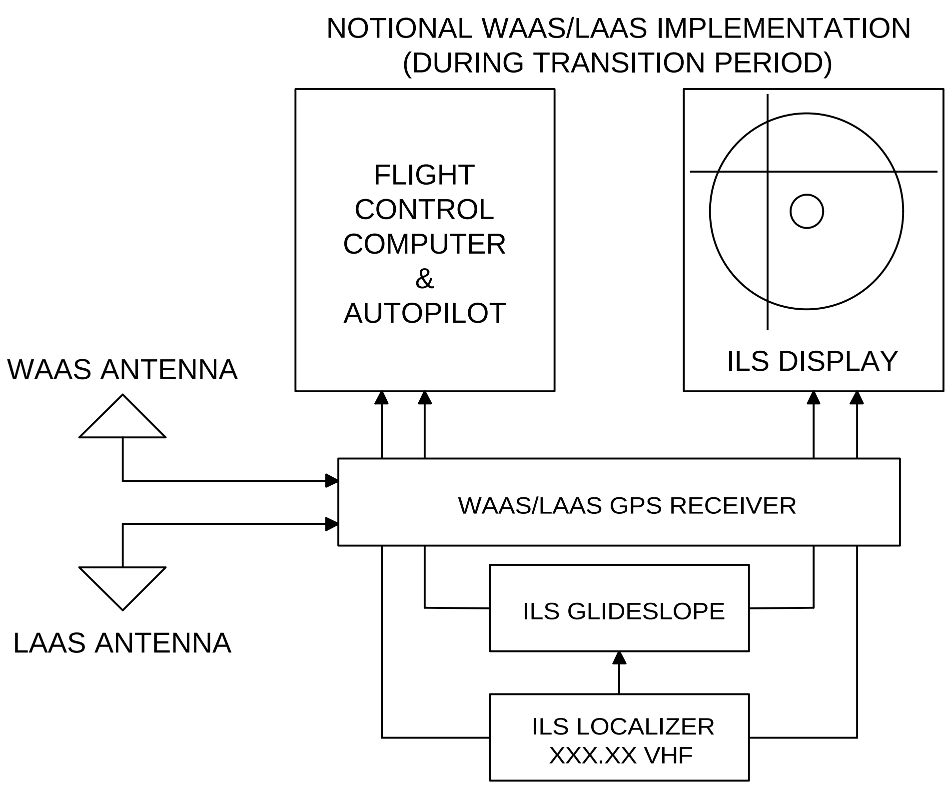
The total cost for the above modifications is $10K per aircraft. No additional cost is allocated for the down-time associated with accomplishing these tasks as they are expected to be piggy-backed with regularly schedule maintenance (i.e. “C checks”, etc.).

Figure 6.1 Avionics Diagrams





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6.1.4.3 Software: The cost estimate for software is based on 25,000 lines of code, which is 25% greater than the amount of code being used in current technology demonstration programs. The software environment is deemed reasonably stable and mature in that the concept of determining differential corrections is well defined and that software for this function has already been coded and demonstrated privately. It is anticipated that the LAAS software development will concentrate on operation of the ground station itself (sensor subsystem selection, failure monitoring, integrity, etc.) which should not be exceptionally complex as the major components generally already contain built-in test and fault detection functions. In addition, LAAS should be able to take advantage of work performed under WAAS, especially in the integrity monitoring area. The cost estimate was determined by the following calculation:

25,000	lines of code
÷25	lines programmed per day
=1,000	# of workdays required
5	# of years at 200 workdays/year (out of 240 days available)
=$1,000	cost ($K) at $100K per programmer/year w/100% overhead

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This results in $2,000K for two contractors in FY97, and results in an average cost per line of code equal to $40. During the year of evaluation, a 50% rewrite of the software is assumed costing $1,000K, which results in an overall average of $60 per line of code. The winning contractor continues to rewrite code through FY99-FY00 at 50% ($500K) per year. The average cost per line of code for the winning contractor at completion would be $100.

6.1.4.4 Integration and Assembly: Due to the possibly unique characteristics of the evaluation prototypes, an additional 50% of the hardware cost is assumed to be required for integration of the components of the ground station. The production configuration of the ground station equipment is expected to be modular line replaceable units that are mounted in a standard electronics rack, and so does not carry this particular cost. A number of the SCAT I ground station units are similarly configured and have ample expansion space for the required CAT III redundancy. The cost for assembling the production units is contained in 6.1.12 Site Activation.

6.1.4.5 Technology Refresh: The ground station processing and control unit contains four independent microprocessor systems with memory, hard disk storage, and data input/output, along with a backplane that concentrates and routes the electronic signals being generated. Given the recent speed with which microprocessor and disk technology is being superseded, these subsystems are assumed to require replacement every five years at $25K per station. At the same time, the batteries in the uninterruptable power supply will be replaced at a cost of $5K per unit. An additional figure of $129K per year (system-wide) to accomplish this refresh was calculated by ALM. Since microprocessor design tends to be backwards compatible for software, software update for the purposes of refresh is not anticipated due the difficulties of certification.

6.1.5 Testing

6.1.5.2 Development Test and Evaluation: For each of the six prototype systems in FY98, testing was assumed to cost an additional 100% of the hardware and installation costs ($200K and $50K respectively).

6.1.5.3 Operational Test and Evaluation: Similar to above, 100% of the hardware and installation costs for three systems is estimated for operational testing in FY00.

The combined amount of hardware acquisition, assembly, integration, and testing for each contractor's rapid prototype system equals $1,800K (excluding software development costs). This compares to the $1,000K being spent by the Swiss airline Crossair for their SCAT I system effort at Lugano Airport.

6.1.6 Data

6.1.6.1 Technical Manuals: The components of the ground station are mostly off-the-shelf, and are anticipated to have built-in status and health indicators, greatly simplifying the task of maintenance troubleshooting. The operation of the ground station is autonomous and only requires monitoring of its status by tower personnel. As such, the manufacturers' current technical manuals for component description should be adequate. Similarly, the manual requirements for maintenance troubleshooting should be relatively modest, concentrating on isolating and removing the failed LRU. Therefore, a cost of $5K per site was allocated for technical manuals.

Procurement of other types of data is not anticipated. Once the ground station software has been deemed operationally suitable, certified, and purchased, further modification/maintenance of the source code is inadvisable. Replacement of the microprocessors running the software should not require a new software version if accomplished properly, avoiding the elaborate certification process required for each rewrite.

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6.1.7 Training

6.1.7.2 Course Development: As previously mentioned, the ground station operation is autonomous. Training in its characteristics for airport personnel would be limited to a general GPS and differential corrections overview/familiarization, with most of the course devoted to maintenance actions and troubleshooting.

6.1.8 Integrated Logistics

1.8.2 Maintenance Planning: The estimate of $17K for the system as a whole was developed by ALM.

6.1.9 Peculiar Support Equipment

Support equipment unique to the LAAS ground station is not anticipated.

6.1.10 Common Support Equipment

Fault isolation will determined at the LRU level by built-in test and status monitoring, therefore common support equipment is not anticipated.

6.1.11 Industrial Facilities

Industrial facilities are not applicable to the LAAS program.

6.1.12 Site Activation

6.1.12.5 Site Installation and Checkout: An estimate of $20K per site was used for the installation and checkout of the LAAS equipment. This is comparable to the installation of a high-end LAN server and related equipment, which is reasonably analogous to the LAAS equipment. The antenna locations do not have to be surveyed separately for latitude and longitude separately since the ground station equipment will be able to self-calibrate during setup. Existing ILS infrastructure (shelters, power, cabling, etc.) is expected to be utilized extensively.

6.1.13 Initial Spares

A replacement for each of the major subsystems or components was provided as initial spare for each ground station as follows:

Processing & Control Unit (1 CPU + 1 backplane)	$10,000
GPS Sensor	$25,000
GPS Antenna Assembly	$5,000
L1 Transmitter w/antenna	$5,000
10% of above	$5,000
Total	$50,000

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The processing and control unit spares are again supplied after each technology refresh is accomplished.

6.1.14 Operational Support

6.1.14.1 Contractor Maintenance: It is assumed that the manufacturer will provide support for the ground station for the first year. 3SNavigation quotes 15% of the hardware price for one year of inclusive maintenance for their GPS ground reference system, and this percentage was used for the expected hardware cost of $200K per ground station.

Based on ground station component lists and anticipated mean time between failure statistics supplied by SETA, ALM parametrically determined the recurring costs contained in the remainder of the operational support figures shown, with the exception of 6.1.14.10 Flight Inspection Procedures, which is addressed below.

6.1.14.10 Flight Inspection Procedures: The flight inspection requirements for LAAS implementation are still undetermined at this point. To be conservative, one TERP and one flight check per ground station were costed. The rates were $16K and $2.5K respectively and are taken from figures quoted in the WAAS CBA.

6.1.15 Facility Construction

Some construction is anticipated at each LAAS location. Modification of the existing ILS shelter, pouring of concrete stands for the external antennas, and some trenching of new cables is expected. $30K per site has been estimated to cover the cost of these activities.

6.2 Benefits Estimating Methods and Data Sources

6.2.1 User Benefits

Calculable user benefits were found to be available in two categories, efficiency and avionics cost savings.

6.2.1.1 Efficiency

Disruption to flight operations will be minimized at airports with LAAS capability. At outlying airports which currently have CAT I ILS, the LAAS will take the place of ILS and provide essentially the same service but with higher availability because of the more reliable and less maintenance intensive equipment. At current CAT II/III ILS equipped airports, LAAS will replace current ILS equipment.

Efficiency: Efficiency benefits were found to be available from reduced disruptions to flight operations. Disruption occurs when there is an interruption to a planned or optimum flight path. It consists of delay, diversion or cancellation.

Delay is any phenomenon that increases flight time or distance; which in turn causes the user to burn additional fuel. It also causes personal delay time to the user's customers. That is calculated as the value of time of travelers. Delay is the least severe category of disruption.

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Diversion occurs when weather or some other occurrence precludes landing at the intended destination and the flight must continue to an alternate airport to land. Diversion is the most expensive of the disruption types.

Cancellation occurs when an aircraft is unable to depart from the originating airport for weather or other reasons. In this case the entire flight mission is aborted. All incoming revenue is lost, but it is partially offset by savings of fuel and other operating costs.

To measure the difference between disruption that could be expected with and without LAAS, each candidate airport's individual weather data was used in a computer spreadsheet, showing percentage of time the various weather conditions exist. To this, each airport's landing traffic numbers were added by aircraft category. A computation was made to determine what percentage of the airport's traffic would not be able to land if LAAS were not installed as well as the number of landings would not be able to land if LAAS were installed. For example, if a candidate airport were currently CAT I equipped and it was intended that LAAS CAT III would be installed, then the percentage of time the weather at the airport is below CAT I, but at or above CAT III, is the percentage of additional time it would be expected that landings could be made at the airport. A like percentage of the expected aircraft landing traffic demand would be able to land at the airport, where without CAT III it would not have been able to do so.

It is expected that LAAS CAT II equipment will also have CAT III capability, so at all CAT II candidate airports, CAT III benefits are available, and have been taken as benefits in this study. However, since LAAS will not be expected to permit CAT IIIc operations, that is, landings in zero visibility and zero ceiling weather conditions, only 70 percent of the weather below CAT II was considered suitable to provide landing benefit from LAAS.

The second aspect of efficiency benefit is that of shortened or curved approach path. Current precision landing equipment, notably the ILS, requires approximately five miles of stable straight-in controlled flight on the glideslope before landing. LAAS technology does not have this straight-in requirement and can allow both shorter turns onto final approach and also curved approaches. In the most likely case, it was assumed that final approach could be shortened by approximately 2 miles or one minute on final approach. It was reasoned that shortened approach path, however, may not be available at many airports because of geographic restrictions, noise abatement considerations or volume of traffic. Therefore, an efficiency benefit equal to only one half minute of flight time was assigned in the most likely benefits. No shortened approach benefit at all was claimed for the low benefit option and for the high benefit option, the full one minute was claimed.

At airports, notably on the outlying reception areas of WAAS, several CAT I ILSs are replacement candidates with CAT I LAAS. In these cases, no efficiency benefit is claimed except for shortened approach, since the landing capability is already present in its current landing category. While it handled only anecdotally here, there may be some minor benefit at these locations from the fact that the reliability of the LAAS equipment is expected to be higher than the reliability of ILS and the small delta between the two from this added "on the air" time, could provide some small benefit to users.

Candidate airports were treated individually with their individual climatological weather histories from the "Ceiling-Visibility Climatological Study and Systems Enhancement Factors," Final Report dated June, 1975. These airport specific historical weather data were used in determining the percentage of time each airport experiences the various categories of weather. This individual airport weather information was used at most candidate airports; however, for some airports, no individual history information was available. In those cases, regional weather data for the area was substituted.

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6.2.1.2 Avionics Cost Savings

LAAS avionics are expected to be available as a low-cost software modification to WAAS avionics, since the principles and methods involved are almost identical. When users begin to equip with LAAS instead of ILS avionics, the savings should be substantial. However, the assumption in the study is that users will continue to purchase ILS in new aircraft through mid-2006 and maintain ILS through 2010. Therefore, dual equipage costs are incurred, and the savings in later years do not make up (in present value) for the additional avionics expenses in earlier years. The difference between LAAS and the reference case is therefore treated as a cost rather than as a benefit.

6.2.2 FAA Benefits: O&M Avoided Costs

Eventual decommissioning of the existing ILS components, the functionality of which will be replaced (and enhanced) by LAAS, will yield significant savings to FAA because of the substantially lower annual costs of maintaining the future LAAS complement, versus that of maintaining the existing ILSs. This is attributable to the significantly lower unit cost of annual O&M associated with LAAS, versus the unit costs of maintaining the existing ILSs. The fact that multi-unit ILSs (GS, LOC, OM, MM, IM: required for each runway) with their requisite redundancies, will be replaced by single LAAS ground stations, each of which will serve all runway ends at that site, is also significant.

The assumption that LAAS will enjoy periodic updates as a part of its anticipated O&M costs, will obviate the likelihood of obsolescence typical of long life-cycle government owned and operated hardware and software, which lead to gradually increasing costs of maintenance, difficulties in locating spares, etc.

The basic O&M costs of maintaining the existing complement of ILSs used herein are based on data compiled by the FAA's O&M Team in 1993 (Navigation and Landing Resource Requirements Study), adjusted to appropriate ('95) dollars. These costs fall into several categories, the most significant of which (reasonably corresponding to those used in the O&M costs estimation for LAAS ground stations) are listed below. Also shown is the approximate percentage of the cost attributable to each category. Costs are in 1995 constant dollars (000). The costs below are for glide slopes and localizers; markers (outer, middle, inner) are dealt with separately, assuming one each for each ILS installation.

	Cost	Percent

Maintenance Staffing	$27.38	61.6
Local Consumption	$10.56	23.7
Flight Inspection	$ 3.17	7.1
Logistics Support	$ 3.17	7.1
Operational Support	$ .10	0.2
Training	$ .09	0.2
Total: CAT 1	$44.47	
CAT 2	$53.63	
CAT 3	$62.80	

For markers, the corresponding unit O&M costs (from same source as glide slopes (GSs) and localizers (LOCs)) are estimated as follows:

OM/LOM	$4.77	Notes: includes combined total costs
MM	$3.91	assumes 1 OM/LOM per CAT 1 ILS
IM	$3.91	assumes 1 each OM/LOM, MM, and IM per each CAT II/III ILS

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The appropriate quantities of existing (reference) systems is used, along with the expected ramp-down of these systems expected to occur after implementation of LAAS, in conjunction with foregoing unit costs, to generate the stream of expected savings in O&M costs.

The ramp-up of the expected number of LAAS ground stations is included beginning in the year 2001. The O&M cost of that new inventory is also included.

7.0 Life Cycle Cost Analysis Summary

Costs for 160 LAAS stations were estimated at a total of $176 million (constant 1995), with a present value of $107 million. Costs were broken down as follows:

Category	Constant	Current	Present Value
RE&D	$ 35.0	$ 38.6	$ 27.7
F&E	97.6	117.0	63.4
Tech Refresh	17.3	27.3	5.9
O&M*	26.1	38.8	10.5

*LAAS O&M is shown here as a cost; in the analysis, it is combined with avoided ILS O&M to form the net FAA O&M savings.

Additional costs used in the analysis are shown below.

Category	Constant	Current	Present Value
ALSF-2	$ 163.4	$ 210.3	$ 91.0
RVR	30.8	42.1	15.3
Net Avionics Cost	-95.8	-220.3	13.7

See Appendix C for more detailed cost breakdown.

8.0 Benefits Analysis

User benefits totaled $2.58 billion (constant 1995, including net avionics savings), with a present value of $885 million. Benefits were broken down as follows:

Category	Constant	Present Value
Avoided Disruptions	$ 2,333	$ 847
Shortened Path	38	14
Net Avionics Savings	96	net cost
Net FAA O&M Savings	118	25

See Appendix D for more detailed benefits breakdown.

Some additional LAAS benefits which have not been quantified in this report are as follows:

Benefits of a LAAS-based surface detection system at 66 non-ASDE airports have been estimated at five billion dollars (ref 12). By the time of expected implementation, air carrier aircraft will likely already have data link installed to transmit accurate position information. Costs of the associated ground display and warning equipment have been roughly estimated at one million dollars per site.

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LAAS-based surface navigation, especially if connected to a moving map display in the cockpit, could increase aircrew situational awareness and reduce the probability of surface accidents and/or runway incursions.

It has been estimated that, at some airports, eliminating the ILS localizer and glideslope critical areas would result in a 1 minute reduction in taxi time and reduce the spacing on the final approach by 3 miles.

Airport ground vehicles, such as snowplows and police cars, could be equipped with LAAS for precise positioning during low visibility or when ground references are covered.

Helicopter operations to heliports, hospital landing pads, and accident sites could be made safer and more efficient with LAAS position information.

9.0 Cost/Benefit Analysis

Benefits to the FAA and to aviation users outweigh the FAA and user costs to achieve these benefits. The present value of benefits to aviation users are an estimated $860 million over the 2001-2017 time period, with an additional $25 million of FAA net maintenance savings. By contrast, identified FAA and net user expenditures are estimated at $211 million (PV). The NPV is $674 million and the B/C is 4.2. These benefits are based on the ground rules and assumptions listed above and do not include any additional quantified benefits for LAAS flexibility, ground navigation capability, or vertical flight operations.

10.0 Sensitivity and Risk Analysis

To be provided.

11.0 Conclusions and Recommendations

Expansion of precision landing capabilities in the NAS provides substantial user benefits. The recommended method of expansion is with LAAS. Quantified benefits of LAAS are slightly greater than those of ILS expansion, and the omnidirectional coverage and lower unit cost of LAAS give it the potential to enable considerable benefits beyond those quantified in this report.

Appendix A: Definitions

ACCURACY - The degree of conformance between the estimated or measured position and/or velocity of a platform at a given time and its true position or velocity.

AUGMENTATION - Technique of providing the GPS with input information, in addition to that derived from the main GPS constellation in use, which provides additional range (pseudorange) inputs or corrections to, or enhancements of, existing pseudorange inputs. This augmentation enables the system to provide performance enhanced relative to that possible with the basic GPS satellite information only.

AVAILABILITY - Probability that the navigation and fault detection functions are operational and that the signal accuracy, integrity, and continuity of function requirements are met.

CARRIER-PHASE DIFFERENTIAL AUGMENTATION - Use of the wavelength of the signal carrying GPS coded information to provide additional accuracy and/or integrity.

CATEGORY I (CAT I) PRECISION APPROACH - A precision approach procedure which provides for approach to a height above touchdown of not less than 200 feet and with runway visual range of not less than 2,400 feet (with touchdown zone and centerline lighting 1,800 feet Category A, B, C; 2,000 feet Category D).

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CATEGORY II (CAT II) PRECISION APPROACH - A precision approach procedure which provides for approach to a height above touchdown of not less than 100 feet and with runway visual range of not less than 1,200 feet.

CATEGORY III (CAT III) PRECISION APPROACH:
- IIIA.- A precision approach procedure which provides for approach without a decision height minimum and with runway visual range of not less than 700 feet.
- IIIB.- A precision approach procedure which provides for approach without a decision height minimum and with runway visual range of not less than 150 feet.
- IIIC.- A precision approach procedure which provides for approach without a decision height minimum and without runway visual range minimum.

CODE-BASED DIFFERENTIAL AUGMENTATION - Comparison of known position of a ground station to GPS-derived position, resolution of differences into satellite-by-satellite corrections, and transmission of the corrections.

COMMERCIAL OFF THE SHELF (COTS) - Equipment fully developed and manufactured by a commercial vendor and for sale to the general public in the course of normal business operations at prices based on established catalog or market prices.

CONTINUITY OF FUNCTION - Probability that the signal supports navigation accuracy and integrity requirements for the duration of the intended period of operation.

DIFFERENTIAL - A technique used to improve radionavigation system accuracy by determining positioning error at a known location and subsequently transmitting the determined error, or corrective factors, to users of the same radionavigation system, operating in the same area.

GLOBAL POSITIONING SYSTEM - A space-based positioning, velocity, and time system composed of space, control, and user segments. The space segment is composed of 24 satellites in six orbital planes. The control segment consists of five monitor stations, three ground antennas, and a master control station. The user segment consists of antennas and receiver-processors that provide positioning, velocity, and precise timing to the user.

INTEGRITY - The ability of a system to provide timely warnings to users when the system should not be used for navigation.

NONPRECISION APPROACH - A standard instrument approach procedure in which no electronic glide slope is provided (e.g., VOR, TACAN, Loran-C, or NDB).

PRECISION APPROACH - A standard instrument approach procedure in which a course and glideslope/glidepath are provided (e.g., ILS).

PRIMARY MEANS OF NAVIGATION - An approved navigation system that can be used for specific phases of air navigation in controlled airspace without the need for any other navigation system.

PSEUDOLITE - A ground-based transmitter which transmits in-band GPS-like signals. A pseudolite can be used as a data link (to transmit differential corrections and integrity status to user platforms) and as a ranging source. Pseudolites used as ranging sources can improve system accuracy by improving the local constellation geometry and can improve system availability by increasing the number of ranging sources. Pseudolites can be used with code-based and carrier-phase DGPS systems.

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PSEUDORANGE - The distance between a user and a ground-based and/or space-based signal source plus an unknown user clock offset distance.

RADIONAVIGATION [RTCA GNSS Report] - The determination of position, or the obtaining of information relating to position, for the purposes of navigation by means of radio waves.

SUPPLEMENTAL AIR NAVIGATION SYSTEM - An approved navigation system that can be used in controlled airspace of the National Airspace System in conjunction with a primary means of navigation.

Appendix B: Life Cycle Benefit Analysis Details

Unit Values Used in Quantification of User Benefits of LAAS

Virtually all basic unit values relating to aircraft direct operating cost (ADOC), typical numbers of passengers (accounting for aircraft size and average load factors), and passenger value of time (PVT), by primary user group)air carriers. air taxi/commuters, general aviation, military), came from the *FAA/APO's Critical Values Update:* Final APO Report - 10/89 - Update Methodology, and APO forecast update of mid-1995. This appendix summarizes the values and manner in which they were modified and used, not only user group-specifically, but also (to some degree) site-specifically.

Site-specific elements are those which significantly affect the bottom line sum-total of the benefits expected to be realized. These include (among others) forecast activity (by user group and year), usually in terms of "Number of Annual Operations," and average passenger load (enplanements, varying greatly within the air carrier user group) for each site, both of the foregoing obtained from the FAA/APO's Terminal Area Forecast (TAF). It is noted that site-specific adjustment of both of these variables for the air carrier activity has a pronounced effect on the bottom line site-specific results. However, use of fleet-wide average values for the other user groups is necessary, as group and site specifics are not generally available (for other than air carriers).

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The other site-specific variable of consequence is weather; more specifically, the average annual incidence of specific weather categories. These are obtained from the *"Ceiling-Visibility Climatological Study and System Enhancement Factors"* 1975 compiled by the National Climatic Center in Asheville, N.C.

Related to weather, is each site's existing (or baseline) capability and that expected to be achieved with implementation of LAAS. This "delta" represents a proportion of the site's annual activity which can be expected to generate the "averted flight disruptions" to be quantified.

An additional source of input is another FAA/APO document: *"Establishment and Discontinuance Criteria for Precision Landing Systems"* FAA-APO-83-10. From that document, the over-all distribution of the three different kinds of flight disruptions (delay, diversion, and cancellation) is extracted. Also shown is the over-all distribution's counterpart in weather at or below precision minimums, and the "in-between" distribution deemed appropriate for all IMC. All are decimal percentages:

Over-all:	Delay:	.9756	Diversion:	.0057	Cancellation	.0187
Below Precision Mins:		.80		.04		.16
IMC:		.90		.02		.08

The foregoing document also provides guidelines for quantifying diversions and cancellations (for air carriers). These are best described as (for cost of PVT) equivalent delay of 4 hours (for diversions) and 5 hours (for cancellations); supplemented by (cost of ADOC) equivalent of 1.5 hours (for diversions); and additional passenger handling costs of $100 and $70 (each) for diversions and cancellations, respectively. For the purpose of this quantification, the potential ADOC saving (in the case of cancellation, not making the trip) is roughly offset by loss of revenue (assumed percentage of passengers choosing alternate means for their trips).

This results in unit costs of approximately $28,850 per average air carrier diversion, and $27,000 per average air carrier cancellation.

The average delay is assumed to be 0.2 hours (12 minutes), resulting in a unit cost of $2,950. This value is used for the most likely (ML) and low (LO) estimates. For the high (HI) estimate, 30 minutes average delay is assumed.

The shortened (or curved) approach benefit (as described in section 6.2.1.1, Efficiency) is used in full for the high benefit estimate; 1/2 of that for the most likely benefit estimate; and is assumed to be zero for the low benefits estimate.

The over-all unit values used, and the resulting weighted (for most likely and low, use 80/4/16; for high, use 90/2/8) disruption costs are computed as follows:

User Group	ADOC	Pax	PVT	ML	Low	Hi
Air Carrier	$1900	100	$40	$6,418	$3,799	$7,834
AT/Comm	$300	18	$41	$11,67	$687	$1,416
Gen. Av.	$150	4.5	$100	$463	$463	$521
Mil.	$1000	na	na	$686	$686	$831

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The site-specific adjustment accounts for air carriers' varying numbers of passengers and ADOC (from the over-all 100 and $1900) via the following linear relationship of passengers (ranging from 50 to 200, viz. nominal 100; and concurrent ADOC from $1200 to $3200, viz. nominal $1900). This relationship uses solely the (year 2005) forecast AC enplanements; to generate a simple multiplier for the over-all AC weighted "cost per disruption" as computed.

Multiplier F = (Site Passenger Enplanements + 11.25)/ 111.32

This factor was generated off-line for all candidate sites and is entered in the Flight Disruption Quantification Spreadsheet.

Appendix C: Life Cycle Cost Estimate

Table C1, Life Cycle Cost Estimate for LAAS Ground Station, FY96-FY06

	FY96	FY97	FY98	FY99	FY00	FY01	FY02	FY03	FY04	FY05	FY06
1.1 Project Management	500	1,000	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,000
1.2 Systems Engineering	5,500	6,500	8,000	8,500	8,500	8,500	2,500	2,500	2,500	2,500	1,500
1.3 Pre-Production Systems											
1.3.2 Rapid Prototype			1,500		600						
1.3.3 Prototype System				750							
1.4 Prime Mission Equipment											
1.4.1 Hardware						8,000	8,000	8,000	8,000		
1.4.3 Software		2,000	1,000	500	500						
1.4.4 Integration and Assembly			600	300							
1.4.5 Technology Refresh											1,329
1.5 Testing											
1.5.2 Developmental Test & Eval.			1,500								
1.5.3 Operational Test & Eval.					750						
1.6 Data											
1.6.1 Technical Manuals						200	200	200	200		
1.7 Training											
1.7.2 Course Development					200						
1.7.3 Course Delivery & Conduct						200	200	200	200		
1.8 Integrated Logistics											
1.8.2 Maintenance Planning						17	17	17	17	17	17
1.12 Site Activation											
1.12.5 Site Installation & Checkout						800	800	800	800		
1.13 Initial Spares						2,000	2,000	2,000	2,000		400
1.14 Operational Support											
1.14.1 Contractor Maintenance						1,200	1,200	1,200	1,200		
1.14.2 Direct Work Maintenance						98	188	278	368	393	393
1.14.3 Supply Support						73	143	210	277	296	296
1.14.5 Training						17	35	52	69	69	69
1.14.7 Leases and Utilities						24	48	72	96	96	96
1.14.9 Technical Data						40	40	40	40	40	40
1.14.10 Flight Inspection Procedures						740	740	740	740		
1.15 Facility Construction						1,200	1,200	1,200	1,200		
Totals in FY95 $	6,000	9,500	14,100	11,550	12,050	24,609	18,811	19,009	19,207	4,911	5,140
Then-Year Totals	6,168	10,039	15,318	12.899	13,834	29,044	22,823	23,709	24,626	6,473	6,964
Present Value Totals	5,607	8,298	11,510	8,811	8,591	16,398	11,715	11,063	10,447	2,497	2,442

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Table C1 (continued), Life Cycle Cost Estimate for LAAS Ground Station, FY07-FY17

	FY07	FY08	FY09	FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17	TOTAL
1.1 Project Management	300	300	300	300	300	300	300	300	300	300	300	
1.2 Systems Engineering	200	200	200	200	200	200	200	200	200	200	200	
1.3 Pre-Production Systems												
1.3.2 Rapid Prototype												
1.3.3 Prototype System												
1.4 Prime Mission Equipment												
1.4.1 Hardware												
1.4.3 Software												
1.4.4 Integration and Assembly												
1.4.5 Technology Refresh	1,329	1,329	1,329		1,329	1,329	1,329	1,329		1,329	1,329	
1.5 Testing												
1.5.2 Developmental Test & Eval.												
1.5.3 Operational Test & Eval.												
1.6 Data												
1.6.1 Technical Manuals												
1.7 Training												
1.7.2 Course Development												
1.7.3 Course Delivery & Conduct												
1.8 Integrated Logistics												
1.8.2 Maintenance Planning	17	17	17	17	17	17	17	17	17	17	17	
1.12 Site Activation												
1.12.5 Site Installation & Checkout												
1.13 Initial Spares	400	400	400		400	400	400	400		400	400	
1.14 Operational Support												
1.14.1 Contractor Maintenance												
1.14.2 Direct Work Maintenance	393	393	393	393	393	393	393	393	393	393	393	
1.14.3 Supply Support	296	296	296	296	296	296	296	296	296	296	296	
1.14.5 Training	69	69	69	69	69	69	69	69	69	69	69	
1.14.7 Leases and Utilities	96	96	96	96	96	96	96	96	96	96	96	
1.14.9 Technical Data	40	40	40	40	40	40	40	40	40	40	40	
1.14.10 Flight Inspection Procedures												
1.15 Facility Construction												
Totals in FY95 $	3,140	3,140	3,140	1,411	3,140	3,140	3,140	3,140	1,411	3,140	3,140	175,969
Then-Year Totals	4,374	4,496	4,622	2,135	4,884	5,021	5,162	5,306	2,451	5,608	5,765	221,721
Present Value Totals	1,394	1,303	1,218	511	1,064	994	929	868	365	758	709	107,493

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Table C2, LAAS Fleet Size & Costs for Avionics, FY97-FY06

	FY97	FY98	FY99	FY00	FY01	FY02	FY03	FY04	FY05	FY06
<u>Current Fleet Retirements</u>										
Air Carrier Cat II	1,670	-66	-64	-61	-59	-56	-54	-52	-50	-48
Air Carrier Cat III	1,670	-66	-64	-61	-59	-56	-54	-52	-50	-48
Air Taxi Cat II	644	-25	-24	-23	-22	-22	-21	-20	-19	-18
G/A Cat II	2,727	-109	-104	-100	-96	-92	-89	-85	-82	-78
<u>New Acquisitions</u>										
Air Carrier Cat II	0	113	113	113	113	113	113	113	113	113
Air Carrier Cat III	0	113	113	113	113	113	113	113	113	113
Air Taxi Cat II	0	123	123	123	123	123	123	123	123	123
G/A Cat II	0	113	113	113	113	113	113	113	113	113
<u>Fleet Size</u>										
Air Carrier Cat II	1,670	1,717	1,766	1,818	1,872	1,929	1,988	2,049	2,112	2,177
Air Carrier Cat III	1,670	1,717	1,766	1,818	1,872	1,929	1,988	2,049	2,112	2,177
Air Taxi Cat II	644	742	841	941	1,042	1,143	1,245	1,348	1,452	1,557
G/A Cat II	2,727	2,731	2,740	2,753	2,770	2,791	2,815	2,843	2,874	2,909
<u>LAAS Equipage Per Year</u>										
Air Carrier Cat II				113	555	660	660	113	113	113
Air Carrier Cat III				113	555	660	660	113	113	113
Air Taxi Cat II				123	292	415	415	123	123	123
G/A Cat II				113	600	710	710	710	113	113
<u>LAAS Avionics Acquisition</u>										
Air Carrier Cat II ($10K/acft)				1,130	5,550	6,600	6,600	1,130	1,130	1,130
Air Carrier Cat III ($10K/acft)				1,130	5,550	6,600	6,600	1,130	1,130	1,130
Air Taxi Cat II ($3.5K/acft)				431	1,022	1,453	1,453	431	431	431
G/A Cat II ($3.5K/acft)				396	2,100	2,485	2,485	2,485	396	396
Yearly Acquisition Cost (1.4)				3,086	14,222	17,138	17,138	5,176	3,086	3,086
O&M @ 7% of Acq.				216	996	1,200	1,200	362	216	216
Yearly O&M Cost (1.14)				216	1,212	2,411	3,611	3,973	4,189	4,405
Navdata Update @ .57K/acft				263	1,141	1,394	1,394	604	263	263
Yearly Navdata Cost (1.6)				263	1,404	2,798	4,192	4,795	5,059	5,322

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Table C2 (continued), LAAS Fleet Size & Costs for Avionics, FY07-FY17

	FY07	FY08	FY09	FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17
Current Fleet Retirements											
Air Carrier Cat II	-46	-44	-42	-41	-39	-37	-36	-35	-33	-32	-31
Air Carrier Cat III	-46	-44	-42	-41	-39	-37	-36	-35	-33	-32	-31
Air Taxi Cat II	-18	-17	-16	-15	-15	-14	-14	-13	-13	-12	-12
G/A Cat II	-75	-72	-69	-67	-64	-61	-59	-57	-54	-52	-50
New Acquisitions											
Air Carrier Cat II	113	113	113	113	113	113	113	113	113	113	113
Air Carrier Cat III	113	113	113	113	113	113	113	113	113	113	113
Air Taxi Cat II	123	123	123	123	123	123	123	123	123	123	123
G/A Cat II	113	113	113	113	113	113	113	113	113	113	113
Fleet Size											
Air Carrier Cat II	2,244	2,313	2,384	2,456	2,530	2,606	2,683	2,761	2,841	2,922	3,004
Air Carrier Cat III	2,244	2,313	2,384	2,456	2,530	2,606	2,683	2,761	2,841	2,922	3,004
Air Taxi Cat II	1,662	1,768	1,875	1,983	2,091	2,200	2,309	2,419	2,529	2,640	2,751
G/A Cat II	2,947	2,988	3,032	3,078	3,127	3,179	3,233	3,289	3,348	3,409	3,472
LAAS Equipage Per Year											
Air Carrier Cat II	113	113	113	113	113	113	113	113	113	113	113
Air Carrier Cat III	113	113	113	113	113	113	113	113	113	113	113
Air Taxi Cat II	123	123	123	123	123	123	123	123	123	123	123
G/A Cat II	113	113	113	113	113	113	113	113	113	113	113
LAAS Avionics Acquisition											
Air Carrier Cat II ($10K/acft)	1,130	1,130	1,130	1,130	1,130	1,130	1,130	1,130	1,130	1,130	1,130
Air Carrier Cat III ($10K/acft)	1,130	1,130	1,130	1,130	1,130	1,130	1,130	1,130	1,130	1,130	1,130
Air Taxi Cat II ($3.5K/acft)	431	431	431	431	431	431	431	431	431	431	431
G/A Cat II ($3.5K/acft)	396	396	396	396	396	396	396	396	396	396	396
Yearly Acquisition Cost (1.4)	3,086	3,086	3,086	3,086	3,086	3,086	3,086	3,086	3,086	3,086	3,086
O&M @ 7% of Acq.	216	216	216	216	216	216	216	216	216	216	216
Yearly O&M Cost (1.14)	4,621	4,837	5,053	5,269	5,485	5,701	5,917	6,133	6,349	6,349	5,570
Navdata Update @ .57K/acft	263	263	263	263	263	263	263	263	263	263	263
Yearly Navdata Cost (1.6)	5,585	5,849	6,112	6,375	6,639	6,902	7,165	7,429	7,692	7,692	6,814

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Table C3, Life Cycle Cost Estimate for LAAS Avionics, FY00-FY06

		FY00	FY01	FY02	FY03	FY04	FY05	FY06
1.4	Prime Mission Equipment							
	LAAS Acquisition	3,086	14,222	17,138	17,138	5,176	3,086	3,086
	Continued ILS Acquisition	17,100	17,100	17,100	17,100	17,100	17,100	17,100
1.6	Data							
	Electronic Databases	264	915	1,864	2,844	3,850	4,874	5,137
1.7	Training	1,464	3,622	5,276	5,447	5,593	5,691	1,464
1.13	LAAS Initial Spares (11% acq)	339	1,564	1,885	1,885	569	339	339
	ILS Initial Spares	1,881	1,881	1,881	1,881	1,881	1,881	1,881
1.14	Operational Support (7% acq/yr)	216	1,212	2,411	3,611	3,973	4,189	4,405
	ILS Operational Support	19,150	19,727	20,334	20,962	21,612	22,283	22,976
	Total	43,500	60,243	67,889	70,868	59,754	59,444	56,389
	Present Value	31,015	40,143	42,278	41,246	32,502	30,218	26,790

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Table C3 (continued), Life Cycle Cost Estimate for LAAS Avionics, FY07-FY17

		FY07	FY08	FY09	FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17	Total
1.4	Prime Mission Equipment												
	LAAS Acquisition	3,086	3,086	3,086	3,086	3,086	3,086	3,086	3,086	3,086	3,086	3,086	
	Continued ILS Acquisition												
1.6	Data												
	Electronic Databases	5,401	5,664	5,927	6,191	6,454	6,717	6,981	7,244	7,507	7,507	7,507	
1.7	Training	1,464	1,464	1,464	1,464								
1.13	LAAS Initial Spares (11% acq)	339	339	339	339	339	339	339	339	339	339	339	
	ILS Initial Spares												
1.14	Operational Support (7% acq/yr)	4,621	4,837	5,053	5,269	5,485	5,701	5,917	6,133	6,349	6,565	6,781	
	ILS Operational Support	23,689	24,423	25,178	25,944								
	Total	38,601	39,814	41,048	42,294	15,365	15,844	16,324	16,803	17,282	17,498	17,714	696,671
	Present Value	17,139	16,521	15,919	15,329	5,205	5,016	4,830	4,646	4,466	4,226	3,998	341,487

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Appendix D: Cost-Benefits Analysis

To be provided.

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Appendix E: Risk Analysis
To be provided.

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Appendix F: References

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